AD-773 601

RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

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Prepared for:

Advanced Research Projects Agency
Army Research Office

31 August 1973

Unclassified
Security Classification

AD 773601

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Polytechnic Institute of Brooklyn 333 Jay Street Brooklyn, New York 11201	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

SEMI-ANNUAL TECHNICAL SUMMARY OF RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Semi-Annual Technical Summary for period ending August 31, 1973

5. AUTHOR(S) (First name, middle initial, last name)

Principal Investigator: Martin H. Bloom

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
	12 21	0

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
DAHC04-69-C-0077 b. PROJECT NO. ARPA Order No. 1442, Amendment 5 c. Program Code No. 62301E d.	PIBAL REPORT NO. 73-B 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Advanced Research Projects Agency and U.S. Army Research Office

13. ABSTRACT

This report contains a description of the technical problem areas and accomplishments achieved during the reporting period. In addition, a complete list of public ions, presentation, lectures, etc. is included and the personnel ssociated with the program are listed. The research projects are in the general subject areas of fluid and plasma dynamics. The work described was carried out under an ARPA contract, Order No. 1442, Amendment 5.

DD FORM 1 NOV 68 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Laser diagnostics Plumes Stratified flow						

SEMI-ANNUAL TECHNICAL SUMMARY OF RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

for the period ending 31 August 1973

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
ARPA Order No. 1442, Amendment 5
Program Code 62301E

Date of Contract: 1 September 1969

Expiration Date: 30 June 1974

PIBAL
Report 73-B

for
U.S. Army Research Office
Contract No. DAHC04-69-C-0077

Submitted by: Martin H. Bloom
Principal Investigator
Director of Gas Dynamics
Research
Dean of Engineering

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ACKNOWLEDGMENT

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by U.S. Army Research Office, Box CM, Duke Station, Durham, North Carolina 27706 under Contract No. DAHC04-69-C-0077.

I. INTRODUCTION

The Polytechnic Institute of Brooklyn is conducting an interdisciplinary program involving both theoretical and experimental studies in the areas of aerodynamics, laser development, and turbulence. In particular, those aspects are dealt with which are directly applicable to the immediate and long range interests of the ARPA Strategic Technology Office. Laboratory simulations, experimental devices and comparison of results with observed flight behavior are under consideration. Generation of new ideas and the review and evaluation of research performed by others in the professional community is also a significant part of the research effort.

In addition to the research studies briefly summarized in the following section, the investigators are engaged in ARPA committees and discussions and normally participate in the various workshops and meetings pertinent to the overall program.

II. RESEARCH PROJECTS

In this section, the various technical aspects of the individual research projects are discussed. In addition to a description of the task, the investigators, including faculty and students, and the current effort and major accomplishments to date are described. The various research areas are listed here for reference:

A. Flow Diagnostic Development

B. Entrainment, Vortex Structures and Turbulence

C. Laser Brightness Experiment

D. Multiphase Flow Diagnostics

A. Flow Diagnostic Development

Investigator: Professor S. Lederman

Technical Program and Accomplishments:

With the phasing out of the research effort in the field of electrostatic probes, electron beam diagnostic techniques,[1] microwave plasma interaction phenomena,[2] the emphasis in our research program has been shifted towards the field of laser technology, specroscopy and the application of both the laser technology and spectoscopy techniques towards the diagnostics of flow fields. As indicated in the last progress report, several aspects of these techniques are under investigation in our laboratory. These range from the concentration measurement of specific species in a mixture of gases to the determination of the temperatures of the individual species in a gas mixture at equilibrium and non-equilibrium states; from the determination of the velocity field to the problem of interference of polyatomic molecules as, for example, aluminum oxides which may be present in the exhaust of rockets; from the sizing of particulates to the quantitative measurements of the same; from the diagnostics of a single phase system to the diagnostics of a system consisting of solid, liquid gas and ionized particles. While the major

emphasis is, as indicated above, on the diagnostics of flow fields, the effect of interference of other than the neutral gaseous state of matter present in the system is being investigated. The major tool used in our investigation is the Raman scattering technique. Other scattering phenomena like Mie and Rayleigh scattering are also utilized (Doppler velocimeter). As pointed out in the previous progress report, one of the aspects of our work was concerned with the resonant Raman effect. After construction and calibration of the appropriate apparatus experiments are being conducted at present. A report concerning the results of these experiments and a description of the apparatus is now in preparation and should appear shortly.

Also in preparation is a report on the quantitative measurements of the interference effects of aluminum oxide particles on the Raman scattering diagnostics of other species. This report will supplement report No. 72-39.[3] As far as the simultaneous and instantaneous measurements of concentration temperature and velocity at a point are concerned, the apparatus necessary to accomplish this has been constructed, and some preliminary data have been obtained. It has, however, been found that some modifications of the apparatus were necessary concerning the general layout to incorporate a Spex 1402 double monochromator and a number of other receiving stations in order to obtain simultaneously several Stokes and anti-Stokes vibrational and rotational scattered intensities as well as Doppler signals. This has been largely accomplished. The modified apparatus is now being calibrated and data should be obtained during the current reporting period.

References:

1. Lederman, S. and Avidor, J.M.: Slightly Ionized Low Density Hypersonic Flow About a Sharp Plate and Its Diagnostics. Paper presented at the AIAA 6th Fluid & Plasma Dynamics Conference, Palm Springs, California, July 1973.

2. Lederman, S. and Dawson, E.F.: Pulsed Microwave Breakdown in Gases With a Low Degree of Preionization. J. Appl. Phys., 44, 7, pp. 3066-3073, July 1973.

3. Lederman, S.: Raman Scattering Diagnostics in the Presence of Al_2O_3. PIBAL Report No. 72-39, December 1972.

B. Entrainment, Vortex Structures and Turbulence

Investigator: Professor P.M. Sforza

Technical Program and Accomplishments:

Nonhomogeneities introduced by density variations due to upstream flow stratification and/or heat transfer within the fluid are important factors in the turbulent mixing process. Such effects are prevalent in undersea flow fields. In addition, complications due to three-dimensional aspects of body geometry and upstream flow nonuniformities must be taken into account.

The experimental program on turbulent mixing and entrainment reflects concern for these effects. A small (one foot diameter) wind tunnel has been modified to provide more uniform upstream conditions for investigations of the effects of heat transfer in the wake of heated axisymmetric and non-axisymmetric bodies. Experiments in this facility are scheduled to begin shortly. A large (4 foot by 5 foot) wind tunnel with density stratification and upstream shear profile generation capability will be utilized to study the effects of these conditions on the flow around and in the wake of bodies with shapes typical of undersea vehicles.

Quantitative measurements and flow visualization studies of transition, ordered vortex structures, and entrainment in nonhomogeneous free shear flows, both axisymmetric and nonaxisymmetric in geometry, are continuing in the Laboratory. Clearly these basic investigations are

pertinent to the more applied studies of undersea vehicles described above, as well as to large scale effects in mixing in the atmospheres typical of fireballs, for example.

Finally, a characteristics program for initial development of blast waves from finite spheres has been completed and appears in Ref. 1. The results of this type of inviscid calculation is of utility in analyzing and developing viscous flow resulting from a blast.

Reference:

1. Truncellito, N.: Unsteady Flows Initiated by Explosion. M.S. (Aeronautics and Astronautics) Thesis, Polytechnic Institute of Brooklyn, June 1973.

C. Laser Brightness Experiment

Investigators: Dr. W. T. Walter and Prof. J.T. LaTourrette

Technical Program and Accomplishments:

Chemical generation of the copper vapor in copper vapor lasers offers dual advantages of a rapid startup time and the preservation of a high electrical efficiency in a flowing copper vapor laser system.[1] Two types of chemical generation have been experimentally tested; a solid fuel propellant seeded with copper particles and a copper thermite. During this reporting period, progress was made on both types of chemical generation. A model was developed to estimate the time required to heat and vaporize a copper particle. Convective heat transfer and both evaporative and radiative heat losses were included. The model indicated that the 30-μ copper seed particles used in the solid fuel propellant which had been tested in an earlier experimental program,[1] were too large to be fully vaporized during the residence time within the gas generator. In fact, less than 1% of the copper would have been vaporized which accounts for the low copper densities measured, 10^{12} Cu atoms/cm^3. The model also indicates that 3-μ copper seed particles, which are

commercially available, would be fully vaporized. Also, initial experiments with copper thermite indicate that molten copper at a temperature of 1600°C can be generated in a few minutes utilizing the reaction,

$$3Cu_2O + 2Al \rightarrow 6Cu + Al_2O_3 + 260.3 \text{ Kcal.}$$

Resumption of the laser brightness experiment has been scheduled for the next reporting period with the installation of an unstable or "high-loss" resonator. During the initial experiments in which a transverse flow was introduced within the optical cavity of a copper vapor laser, very little change was observed in the near-field output beam pattern of the laser. This result is not conclusive, since any turbulence-produced distortion of the laser output waveform might be difficult to distinguish within the non-coherent multimode output of the laser. The optical cavity was a plane-parallel Fabry-Perot, and the output beam divergence was much greater than the diffraction-limit because of the high gain available in the active medium. An effect of the disturbance caused by the introduced flow should be easier to detect if the spatial coherence of the laser were improved. The number of transverse modes oscillating can be reduced to a single one by reducing the effective diameter to 2mm. However, a 2mm transverse dimension is too small to be able to conveniently introduce a controlled transverse flow distribution. Replacement of the Fabry-Perot cavity by a "high-loss" resonator allows utilization of the full 4cm diameter cross-sectional area of the gain volume while, at the same time, reducing the angular divergence of the output to the diffraction limit corresponding to a single transverse mode. A "high-loss" resonator with a large effective magnification factor is relatively insensitive to distortions. The sensitivity to distortion can be increased by decreasing the magnification. These experiments will be carried out during the next reporting period.

Reference:

1. Walter, W.T., Solimene, N. and LaTourrette, J.T.: Copper Vapor Generator. Final Report for AFWL under Contract F29601-72-C-0080, 31 August 1973.

D. Multiphase Flow Diagnostics

Investigators: Prof. R.J. Cresci and Mr. E.J. Kawecki

Technical Program and Accomplishments:

The Raman measurements of nitrogen gas, water liquid and vapor, as discussed in the previous technical summary, were conducted. The scattered intensities of nitrogen gas and liquid water in the calibration apparatus were sufficient for experimental use. However, the Raman signal from the water vapor was not.

The primary difficulty was the relatively insensitive response of available photomultipliers to radiation from the ruby laser-water vapor interaction. To circumvent this problem another laser source is being developed which shifts the water vapor line to lower wavelengths where the monitoring equipment (photomultiplier tube) is more sensitive. The organic dye laser obtained for this purpose required extensive power supply and triggering modifications to adapt it for this work. These modifications are nearly complete.

Work will now be directed towards recalibration of all species with the new laser source in the static chamber.

III. SUMMARY OF RESEARCH PUBLICATIONS

A. Published Articles

R. J. Cresci and J. Starkenberg, "Liquid Film Cooling on Hypersonic Slender Bodies". Astronautica Acta, Vol. 18, No. 1, pp. 11-20, 1973.

The present paper is devoted to an experimental and theoretical study of a liquid coolant (water) injected in the nose region of a slender body, and a study of the behavior of the film over the downstream impermeable surface.

Tests have been performed, on a 20^{o} half-angle cone with a hemispherical nose, at a Mach number of 8 and Re/ft. between 0.2×10^{6} and 1.4×10^{6}.

The analytical approach assumes a "steady" film configuration and includes the effects of vaporization and mass entrainment into the boundary layer. However, the experimentally obtained film behavior is not well-predicted by this simple flow model. An "unsteady" stability analysis was then developed and compared with the experimental results.

E. F. Dawson and S. Lederman, "Pulsed Microwave Breakdown in Gases with a Low Degree of Preionization". Journal of Applied Physics, Vol. 44, No. 7, pp. 3066-3073, July 1973 (PIBAL Report No. 72-14)

This paper presents the results of experiments on microwave breakdown at an open-end waveguide antenna in air, argon, nitrogen, carbon dioxide, and methane at pressures of 0.3 and 30 Torr. The antenna was operated at 9.375 GHz under pulsed conditions at varying pulse rates. Very low degrees of preionization were obtained by adjusting to very slow pulse rates. The power needed to maintain the discharge was measured and from that the electric field strength was calculated. This is presented as a function of pressure for each gas at pulse rates ranging from 10 to 500 pulses/sec. At low pulse rates, significantly

higher power levels are needed to maintain the discharge. An interesting feature is the double minima observed at low pulse rates in the data for breakdown field strength as a function of pressure for carbon dioxide and methane. The data were also used to calculate ionization frequency as a function of effective electric field for all five gases. Where possible, these data are compared with data reported by other investigators.

B. Presentations at Technical Meetings

P.M. Sforza presented a paper entitled "Mass, Momentum, and Energy Transport in Free Turbulent Mixing" at the Fourth Canadian Congress of Applied Mechanics, Montreal, Canada, May 28-June 1, 1973.

J.M. Avidor and S. Lederman are authors of a paper entitled "Slightly Ionized Low Density Hypersonic Flow About a Sharp Plate and Its Diagnostics", which was presented at the AIAA 6th Fluid and Plasma Dynamics Conference, held in Palm Springs, Calif., July 16-18, 1973.

C. P.I.B. Reports, Dissertations and Books

J.T. Kelly, "The Interaction of a Hypersonic Plume With an External Hypersonic Stream". Ph.D. Thesis, June 1973; also, PIBAL Report No. 73-12, July 1973.

Nicholas T. Truncellito, "Unsteady Flows Initiated by Explosion". M.S. Thesis, June 1973.

W.T. Walter, N. Solimene and J.T. LaTourrette, "Copper Vapor Laser" Generator". Final Report for AFWL under Contract F29601-72-C-0080, 31 August 1973.

IV. ARPA-RELATED ACTIVITIES, LECTURES AND CONSULTANTS

A. ARPA-Related Activities

Martin H. Bloom, Dean of Engineering, is a member of the Plume Physics Panel of DARPA/IDA. He is an Army consultant on the Safeguard program. He serves as Editor of the International Journal of Computers and Fluids, which deals with computational fluid dynamics. He is a member of the Educational Affairs Committee of the American Institute of Aeronautics and Astronautics. He has been chosen an Outstanding Educator of America for 1973, an award of national recognition based on exceptional service, achievements and leadership in the field of education, and is featured in the national awards volume of Outstanding Educators of America.

Participation at meetings relevant to the program:

M.H. Bloom, R.J. Cresci and P.M. Sforza were invited participants at the ARPA-APL Joint Workshop on Oceanographic Fluid Dynamics, held at IDA, April 2-4, 1973.

W.T. Walter was invited by the Electro-Optical Program Office of the Naval Research Laboratory to present a briefing at their Blue-Green Laser Technology Review on June 26, 1973 at Washington, D.C.

B. Lectures

W.T. Walter was invited to present a talk entitled "Metal Vapor Lasers" for the Electrical Engineering Colloquium at City College of New York on March 1, 1973.

M.H. Bloom gave an invited address on "The Mechanics of Flow and What It Means to Us" at the 1973 Junior Science Symposium held in Monmouth, N.J., March 9, 1973.

M.H. Bloom presented an invited colloquium on "Viscous Flow Along a Corner: A Story in Fluid Mechanics" at Brown University's Division of Engineering and Applied Mathematics, Providence, R.I., March 30, 1973.

M.H. Bloom gave an invited address entitled "Change in the Engineering World in Relation to Engineering Practice and Education" at the Meeting of American Institute of Consulting Engineers, New York City, May 2, 1973.

Lectures at P.I.B.:

March 1973

Dr. G. Heskestad Factory Mutual Research Corp.	Modeling of Enclosure Fires

April 1973

Prof. R.G.E. Hutter Polytechnic Institute of Brooklyn	Beam-Plasma Experiments
Dr. R. Sedney Ballistics Research Laboratory	Flow Disturbances Caused by Protuberances in Boundary Layers

May 1973

Prof. R.D. Cess State University of New York at Stony Brook	Model Atmospheres of the Major Planets

June 1973

Prof. J. Rom Technion-Israel Institute of Technology	Aerothermochemistry of Fluid Dynamic Lasers

V. PERSONNEL ASSOCIATED WITH THE RESEARCH PROGRAM

Martin H. Bloom	Principal Investigator Director of Gas Dynamics Research Dean of Engineering
Robert J. Cresci	Professor
Edwin J. Kawecki	Research Assistant
Prem K. Khosla	Consultant
Joseph Laiosa	Research Assistant
James T. LaTourrette	Professor
Samuel Lederman	Professor
Otto Meruelo	Graduate Assistant
Christian Rice	Research Assistant
Pasquale M. Sforza	Associate Professor
William Stasi	Research Assistant
William T. Walter	Research Scientist

AD 773601

ADDENDUM to the SEMI-ANNUAL TECHNICAL SUMMARY OF RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

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PIBAL
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Contract No. DAHC04-69-C-0077

Submitted by: Martin H. Bloom
Principal Investigator
Director of Gas Dynamics Research
Dean of Engineering

POLYTECHNIC INSTITUTE OF BROOKLYN

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POLYTECHNIC INSTITUTE OF BROOKLYN

Department of Aerospace Engineering
and Applied Mechanics

ADDENDUM

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PIBAL Report No. 73-B

II. RESEARCH PROJECTS

A. Flow Diagnostic Development

Investigator: Professor S. Lederman

Defense Significance:

The importance of these diagnostic techniques and the information obtainable on those research efforts can be of major significance. It is possible to determine instantaneously and simultaneously not only the composition, temperature and velocity of a complex flow field remotely, but it also permits the determination of the state of a given component of a mixture. This may be of importance in measuring and monitoring the exhausts of rockets and combustors where solid, liquid, gaseous and ionized species may be present. It thus permits a better understanding of the complex processes taking place and may aid in the remote determination of the nature of an unknown flow field.

B. Entrainment, Vortex Structures and Turbulence

Investigator: Professor P.M. Sforza

Defense Significance:

The problems discussed briefly above have direct bearing on the Ivy-Owl and UW programs.

C. Laser Brightness Experiment

Investigators: Dr. W.T. Walter and Prof. J.T. LaTourrette

Defense Significance:

The utility of high-power lasers will depend on their output brightness, or on how closely their operation approaches diffraction-limited performance. Several types of high-power lasers require rapid and intimate mixing of two or more components to produce the excitation reaction. Output beam quality can be affected by: (1) index of refraction gradients, (2) turbulence produced by the mixing, and (3) the resulting high gain of the excited medium. The copper vapor laser has a high gain (4dB/cm), output in the green portion of the visible spectrum (510.6nm) and can be operated in a static or non-flowing configuration. A copper vapor laser is being used as a model for the infrared gas-dynamic and chemical lasers to uncouple and separately investigate the effects of high gain and turbulence in the more tractable visible spectral region.

D. Multiphase Flow Diagnostics

Investigators: Professor R.J. Cresci and Mr. E.J. Kawecki

Defense Significance:

This study is significant in the diagnosis of flows both in and around rocket nozzles (in the plumes produced by the expansion) and in multiphase flows in general. Further information on formation of water droplets or ice crystals can also be obtained.